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Nitrogen Leak Test of Department of Energy Strategic Petroleum Reserve (DOE/SPR) Well 102A at Bayou Choctaw

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Abstract

A nitrogen leak test was made of the Department of Energy Strategic Petroleum Reserve Well 102A at Bayou Choctaw in May-June 1982. The test indicated a well leak rate of 32 bbls/yr of nitrogen at a pressure of 1844 psia, well within the SPR leak rate criterion of 100 bbls/yr. The test was made with a layer of oil above the 14-inch casing hanger seal because previous tests had indicated considerable nitrogen leakage past this seal. If the hanger seal is not repaired or if a layer of oil above the seal is not maintained during operation with a nitrogen or other gaseous blanket, the leak rate past the seal is expected to be much higher than the well leak rate measured.

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Introduction

Bayou Choctaw well 102A is to be used in the development of a 5.0 million barrel ethane storage cavern planned for possible exchange with Allied for their Bayou Choctaw cavern 17. Well 102A was drilled by Technadrill under the supervision of Williams/Fenix and Scisson between March 9 and July 5, 1981. Jacobs/D'Appolonia Engineers (JDE) performed a brine leak test of the well on June 22-25, 1981,which indicated a brine leak rate of 19.3 bbls/yr. On July 6-11, 1981, JDE performed a nitrogen leak test of the well which indicated a large nitrogen leak rate believed due to a faulty 14 inch casing hanger seal.

A second nitrogen leak test was made by POSSI/Sandia between May 25 and June 7, 1982.. Results of this second leak test are discussed herein.

Well Description

A complete description of the well is given in Reference 1, and a schematic is presented in Figure 1. The well is cased to a depth of 2498 feet below the Bradenhead flange with 14-inch line pipe with welded and x-rayed joints. The configurations of the hanging strings at the time of the test were obtained from References 1 and 2. It is noted that the open hole configuration shown in Figure 1 differs from Figure 7 of Reference 1 but corresponds to the drilling history and the borehole geometry log of Reference 1.

Background

A 45 hour brine pressure test of the well was made by JDE on June 22-25, 1981, Reference 3. The test indicated a brine leak rate of 19.3 bbls/yr. In preparation for a nitrogen leak test, the 7-inch hanging string (Figure 1) was removed and the 10 3/4-inch string was pulled and removed until 2988 feet remained in the well. This was done in an attempt to eliminate leaking joints in the 10 3/4-inch casing so the test could be made with nitrogen in the annulus and brine in the hanging string. There were leaks at the joints of the 10 3/4-inch casing remaining in the well so the nitrogen test was made on July 6-11, 1981, with nitrogen in both the 14 x 10 3/4-inch annulus and inside the 10 3/4-inch hanging string to an initial depth of 2777 feet. Following a 14 1/2 hour stabilization period, the pressure decayed at a rate of 0.51 psi/hr over a 72 hour test period. During this test period, a significant leak of nitrogen was noted through a crack in the 20-inch casing about 5 feet below the bradenhead flange. It was believed that this leak was due to a leak from the 14-inch cased hole at the wellhead, probably at the 14-inch casing hanger.

Following this pressure test, the crack in the 20-inch casing at which the leak occurred was repaired and a tapped fitting was installed for access to the 20 x 14-inch annulus. In August 1981, 10 3/4-inch and 7-inch casing was run to achieve the hanging string configuration shown in Figure 1. All joints were torqued to API specifications, and all joints of the 10 3/4-inch casing were tested by Gatorhawk to pressures of 1090-1100 psi, Reference 2. No attempt was made to locate or repair a leak at the 14-inch casing hanger.

On May 4, 1982, a leak test of the 14-inch casing hanger seals (Figure 2) was made by POSSI/Sandia. Nitrogen was injected through a port in the Bradenhead flange into the small cavity between the hanger seal and the upper O-ring seals outside the 14-inch casing. Nitrogen leaked past the upper O-ring seals into the well, but no leak was detected into the 20 x 14-inch annulus. Subsequent tests were made to try to determine if the hanger seal was leaking. The well was pressurized with brine to 600 psi and the pressure in the 20 x 14-inch annulus was observed for several hours. There was no pressure increase in the annulus. The well was then pressurized to 700 psi with nitrogen and there was no immediate indication of pressure increase in the annulus. However, after several hours the pressure in the 20 x 14-inch annulus started rising. This appeared to indicate a relatively insignificant brine leak past the' hanger, but a considerably larger leak of nitrogen after brine on top of the hanger was gone. It was decided that a nitrogen well leak test would be made while keeping the cavity between the hanger and the upper O-ring seals filled with oil.

Test Procedures

The preliminary procedures for the test are outlined in Reference 4. In preparation for the test, all surface piping was disconnected from the wellhead and all piping connections at the wellhead were flanged off with blind flanges. A 2-inch valve was installed on a blind flange at one entry to the 14 x 10 3/4-inch annulus for nitrogen injection. A 2-inch valve and coupling were installed at one entry to the 10 3/4 x 7-inch annulus for hookup to a vacuum truck for brine removal. A I-inch hammer union was installed on the blind flange at the top of the wellhead for wireline access. Provisions were made for connection of Lynes digital pressure probes on the 14 x 10 3/4-inch annulus, the 10 3/4 x 7-inch annulus and the 7-inch string.

Nitrogen was pumped into the 14 x 10 3/4 inch annulus (Figure 1) to a depth of 2700-feet, while brine was removed from the 10 3/4 x 'I-inch annulus. It was planned to weigh the nitrogen used in each 20 feet of the last 100 feet of 14-inch casing and then in each 10 feet of open hole from the casing seat to the 2700-foot depth, in order to obtain detailed borehole volume information. Weight measurements in the casing were unsuccessful because the interface could not be detected. However, interfaces were easily detected in the open hole below the casing seat and weight measurements were made. After the 2700-foot interface depth was reached in the 14 x 10 3/4-inch annulus, the brine discharge was stopped and nitrogen was injected to raise the wellhead nitrogen pressure to 1950 psia with a corresponding wellhead brine pressure of 726 psia.

Subsequent procedures deviated considerably from those of Reference 4 because of problems with the hanging strings as discussed in the following section.

Test

As in previous applications, it was not possible to accurately define borehole volume from the weight measurements of nitrogen injected. However, the results obtained from the measurements provide a general confirmation of previous results of borehole geometry logs and indicate no regions of significant washouts in the borehole.

Following injection of nitrogen to a depth of 2700 feet in the 14 x 10 3/4-inch annulus (Figure 1), and pressurizing the well to 1950 psia nitrogen pressure and 726 psia brine string pressure, the well was shut in overnight. Nitrogen leakage through the 10 3/4-inch string caused an increase in all wellhead pressures, with pressure in the 14 x 10 3/4 annulus increasing to 1988 psia. It became apparent that leakage through the 10 3/4 string would preclude the test originally planned with brine in the 10 3/4 x 7-inch annulus and the 7-inch string. A decision was made to do the nitrogen test with nitrogen in all three casings to a depth of about 2700 feet. A connecting loop was installed at the wellhead between the 14 x 10 3/4-inch and the 10 3/4 x 'I-inch annuli (Figure 1) to equalize pressures in the two annuli. After equalization, the pressure in the two annuli was about 1360 psia, and the interface depth in the two annuli was at 1958 feet. It was estimated that an additional 192 bbls of brine would have to be removed from the well to achieve the desired interface depth of 2700 feet in the two annuli and the 7-inch string. It was further estimated that this could be achieved by lowering the interface in the two annuli to 3390 feet by adding nitrogen and then connecting the 7-inch string to the annuli at the wellhead to allow pressure equalization.

When nitrogen injection into the two annuli was started, brine return from the 7-inch string was slow and the nitrogen pressures increased fairly rapidly. After removing about 25 bbls of brine, the wellhead nitrogen pressure in the 14 x 10 3/4-inch annulus built up to a value of 2062 psia and nitrogen injection was stopped. This pressure exceeded the maximum allowable pressure for the well. The 25 bbls of brine removed should have moved the interfaces in the two annuli down from 1958 to 2245 feet. Based on this interface depth, the wellhead nitrogen pressure corresponded to a casing seat gradient of 0.94 psi/ft. Shortly after stopping nitrogen injection, brine started flowing rapidly from the 7-inch string and filled the 100 bbl volume vacuum truck. The interpretation was that there was a plug in the 7-inch string which had been severely restricting brine flow and that this plug had suddenly broken loose or moved up. The interfaces in the two annuli were at a depth of about 2695-feet.

Nitrogen injection into the annuli was continued. As previously, there was a very low flow of brine from the 7-inch string while the nitrogen pressure built up fairly rapidly. After shut in of the two annuli for a few minutes with wellhead nitrogen pressure at 1950 psia, approximately 75 barrels of brine was again suddenly released. Nitrogen injection was resumed and when the wellhead nitrogen pressure reached about 1650 psia, another 25 barrels of brine was released. The total brine volume removed during this second phase of nitrogen injection was at this point about 200 bbls, slightly more than that previously estimated to be necessary.

An additional loop was installed at the wellhead to connect the 7-inch string to the two annuli (Figure 1) for pressure equalization. Nitrogen was injected until the pressures indicated before complete equalization were 2016 psia in the 14 x 10 3/4-inch annulus, and 1942 psia in the 10 3/4 x 7-inch annulus and the 7-inch string. The well was shut in and the following interfaces were located:

7-inch string	609 foot depth
10 3/4 x 7-inch annulus	3165 foot depth
14* x 10 3/4-inch annulus	3294 foot depth

* open hole diameter at interface depth is 15-inch.

About 3 1/2 days later, after wellhead leaks had been plugged and time had been allowed for temperatures in the well to reach equilibrium, the interfaces were located as follows:

7-inch string	1416 foot depth
10 3/4 x 7-inch annulus	2979 foot depth
14* x 10 3/4-inch annulus	2988 foot depth

A brine volume continuity check was made using the two preceding sets of interface measurements: that is, the brine volume decrease in the 7-inch string corresponding to downward movement of the interface was compared with the volume increase in the two annuli corresponding to upward movement of the interfaces. This check indicated an increase in brine volume of 9.6 bbls between the two sets of interface measurements. This discrepancy is possibly due to interface movements during the first set of measurements soon after shut in, with a 1 1/4 hour lapsed time between locating the interfaces in the two annuli and in the 7-inch string.

During the last interface measurements, the logging tool was lowered to see if a plug in the 7-inch string could be located. The logging tool encountered something fairly solid at a depth of 3350 feet and appeared to be in a sticky or slushy fluid up to 3314 feet.

Following the last interface measurements, the well was shut in for 7 days and pressure readings from probes on the two annuli and the 7-inch string were recorded at 30-minute intervals. An interface log was then run which indicated the following interface locations;

7-inch string	1434 foot depth
10 3/4 x 7-inch annulus	2971 foot depth
14* x 10 3/4-inch annulus	2978 foot depth

A brine volume continuity check using these interface measurements together with the preceding set of measurements indicate a brine volume increase of 0.74 bbls between the two sets of measurements. Making adjustments for a l-foot difference in casing seat depths indicated by the two logs reduces the brine volume discrepancy to 0.54 bbls. The discrepancy is insignificant in consideration of logging inaccuracies and the uncertainty of the open hole diameters.

The depth of the plug during these interface measurements was 3278 feet, down 72 feet from its location during the earlier measurements.

To remove the nitrogen from the well without depressuring the borehole, the wellhead nitrogen pressure in the 7-inch string and the 10 3/4 x 7-inch annulus was bled off to atmospheric, and brine was injected into the 10 3/4 x 7-inch annulus. During injection of the first 200 bbls of brine, wellhead pressure on the 14 x 10 3/4-inch annulus was kept above 1177 psia, corresponding to a minimum casing seat gradient of 0.50 psi/ft with a column of nitrogen. During injection of the third 100 bbls of brine, it was necessary to gradually reduce wellhead pressure on the 14 x 10 3/4-inch annulus to 267 psia to keep pressure in the 10 3/4 x 7-inch annulus low enough for injection with the vacuum truck pump. An additional 33 bbls of brine was injected while the wellhead pressure on the 14 x 10 3/4-inch annulus was reduced to atmospheric. No brine was returned from the 14 x 10 3/4-inch annulus with the 10 3/4 x 7-inch annulus filled with brine, and with maximum available vacuum truck pump pressure on this brine. It is believed this was due to brine injected having a lower density than brine in the bottom of the well which was rising into the 14 x 10 3/4-inch annulus. The total measured volume of brine injected was about 333 bbls, whereas the measured volume removed while filling the well with nitrogen was about 345 bbls. The discrepancy in volume is insignificant in consideration of the crude measurements obtained by gaging volumes in several vacuum truck tanks.

Test Results

Pressure sensors were installed at the wellhead on the 7-inch string and the two annuli at the beginning of the test. Soon after the well was filled with nitrogen, pressurized, and shut in, the pressure sensor on the 7-inch string malfunctioned and no valid data were obtained from this sensor.

Pressure time histories from the probes on the two annuli over the final six days the well was shut in are presented in Figure 3. Both probes are temperature sensitive and results in the figure indicate pressure cycles which are due to daily ambient temperature cycles. The 3 psi difference between test data from these two sensors, though not very significant, can be largely explained by the dead weight test calibration results.

Linear regressions of the pressure results over the six-day period indicate pressure decay rates of 0.449 and 0.427 psi/day, respectively, for the large and small annulus, with corresponding variances of 0.2 and 0.0 psi^2. The difference between decay rates from the two sensors are considered insignificant, particularly in view of the temperature sensitivity of the sensors.

Calculation of leak rate corresponding to pressure decay rate is based on the equation of state:

$$w = \frac{144\ PV}{RT} \tag{1}$$

where

- w weight, lbs
- P pressure, psia
- V volume, ft^3
- R gas constant, 55.159 $ft/^{\circ}R$ for nitrogen
- T temperature, degrees Rankine

If it is assumed that the nitrogen volume is constant (no brine added or subtracted from the well and no changes in well geometry) and the average nitrogen temperature is constant during the test, the weight of nitrogen is **proport ional** to pressure, and the time rate of change of nitrogen weight is proportional to the time rate of change of nitrogen pressure.

$$\frac{dw}{at} = \frac{144\ V}{RT} \times \frac{dP}{dt} \qquad (2)$$

where t time, days

The volume of nitrogen to the interface depths measured just before shut in of the well for the test, calculated from well geometry, is 2027 ft^3. Using this volume in (2) together with an assumed average temperature of $100^{o}F$ and the maximum measured pressure decay rate of 0.449 psi/day yields;

$$\frac{dw}{dt} = \frac{144 \times 2027}{55.159 \times 560} \times 0.449 = 4.243 \text{ lbs/day}$$

At the initial pressure of 1841 psia from Figure 2, the weight of one ft^3 of nitrogen from (1) is 8.582 lbs. The weight loss rate thus corresponds to a loss of volume at initial conditions **of** 0.494 ft^3**/day** or 180.3 ft^3**/yr** or 32.1 **bbls/yr.**

This leak rate of nitrogen corresponds to a much smaller leak rate of oil and is thus well within the SPR well leak rate criterion of 100 **bbls/yr.** It is noted, however, that this test was made with a layer of oil above the **14-inch** casing hanger seal. If the hanger is not repaired, or if a layer of oil above the **14-inch** hanger seal is not maintained during operation with a nitrogen or other gaseous blanket, the leak rate is expected to be much higher.

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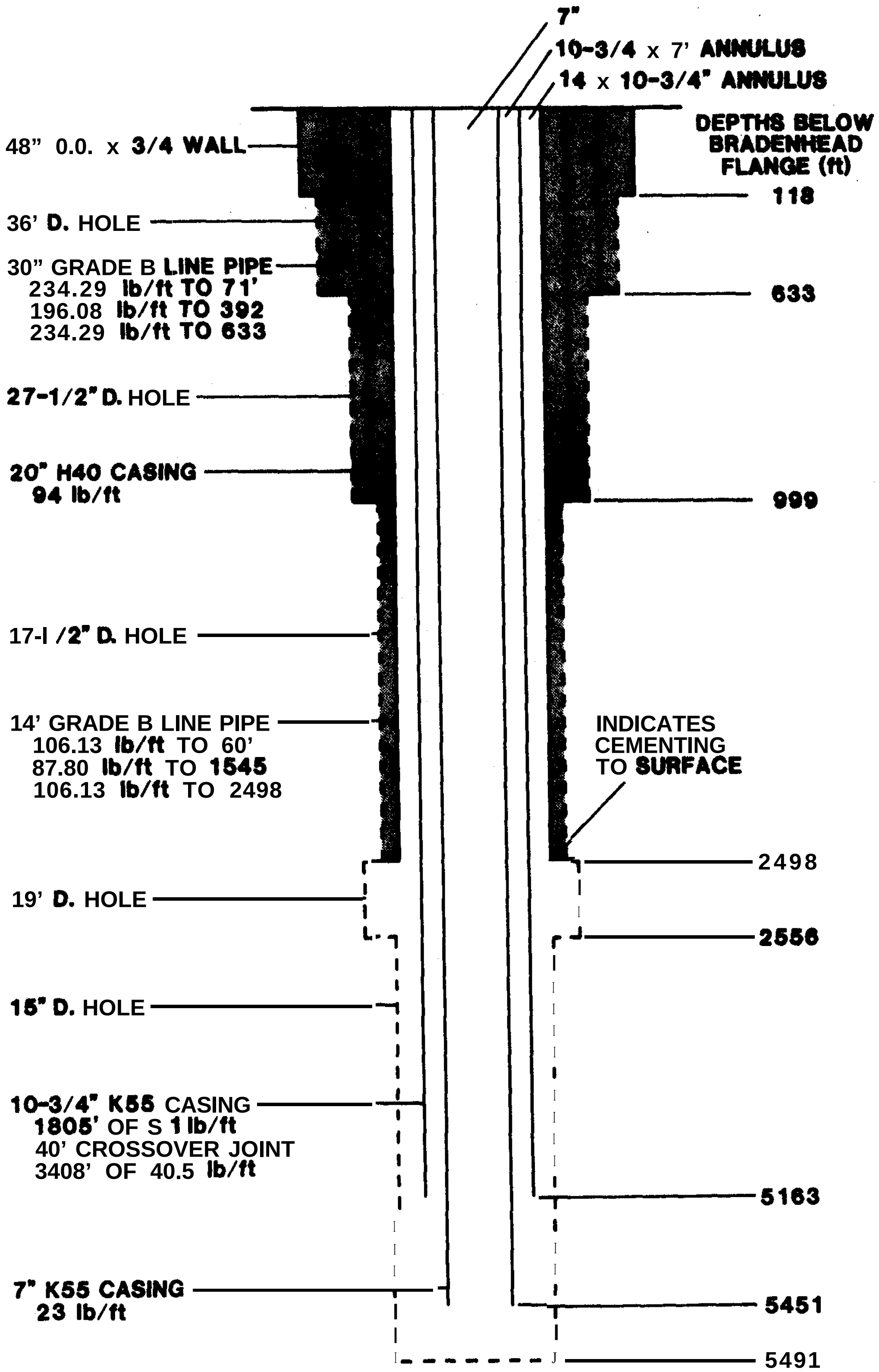

Figure 1. - Schematic of Well with 7-inch and 10-3/4-inch Hanging Strings to Depths Existing During the Test

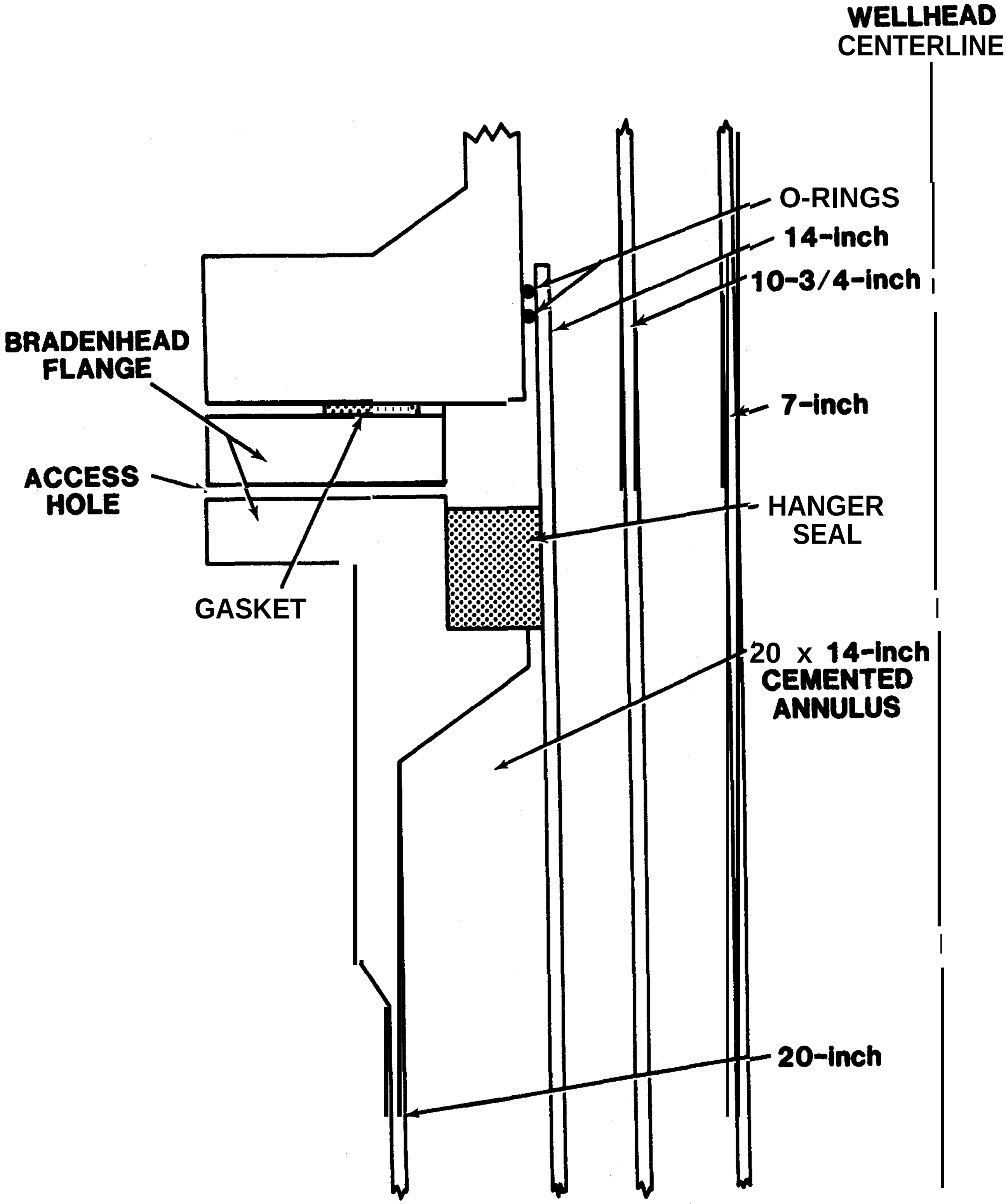

Figure 2. – Schematic of 14-inch Seal Arrangement

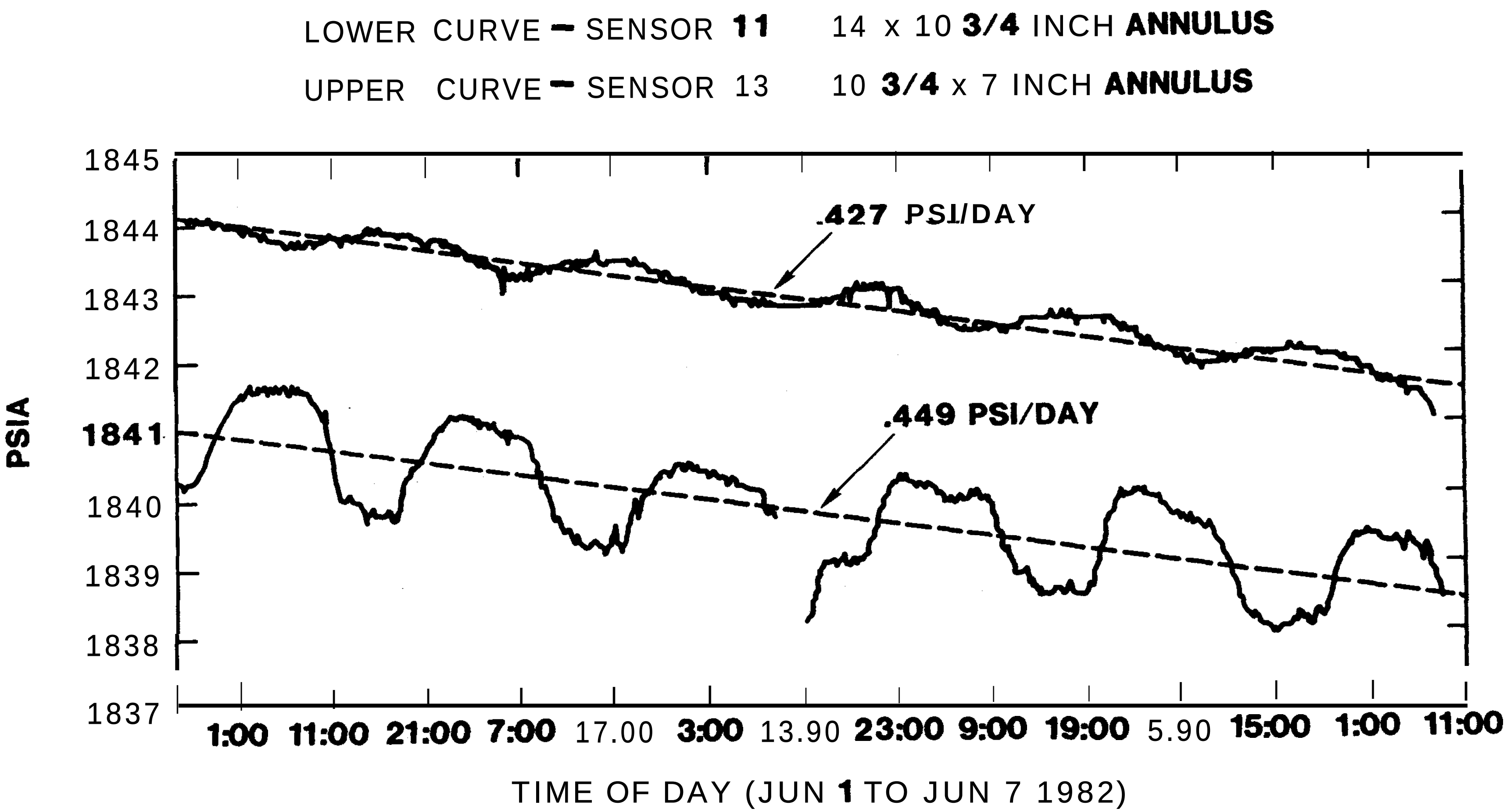

Figure 3. – Wellhead Pressure Measurements

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